

**Evaluation of Ozone Injury  
on Vegetation in the  
Moosehorn National Wildlife Refuge  
Maine**

**2000 Observations**

Submitted to

**The U.S. Fish and Wildlife Service  
Air Quality Branch  
Denver, CO**

Donald D. Davis, Ph.D.

March 5, 2001



**Evaluation of Ozone Injury  
on Vegetation in the  
Moosehorn National Wildlife Refuge  
Maine**

**2000 Observations**

Submitted to

**The U.S. Fish and Wildlife Service  
Air Quality Branch  
Denver, CO**

Donald D. Davis, Ph.D.

March 5, 2001

## TABLE OF CONTENTS

	<u>page</u>
TABLE OF CONTENTS	2
INTRODUCTION	3
General	3
Objectives	3
Justification	3
Diagnosis of Air Pollution Injury	7
Description of Refuge	10
METHODS	14
General Survey Areas	14
Preliminary Selection of Bioindicator Species	14
Air Quality	15
Survey Dates and Locations	17
Severity Rating	17
RESULTS AND DISCUSSION	18
Final Selection of Bioindicator Species	18
Foliar Symptoms	19
SUMMARY	24
RELATED LITERATURE	25
APPENDIX (Species lists)	27

## **INTRODUCTION**

### **General**

Moosehorn is one of more than 500 Refuges in the National Wildlife Refuge System (NWRS) administered by the U.S. Fish and Wildlife Service (FWS). The NWRS is a network of lands and waters managed specifically for the protection of wildlife and wildlife habitat and represents the most comprehensive wildlife management program in the world. Units of the system stretch across the United States from northern Alaska to the Florida Keys and include small islands in the Caribbean and South Pacific. The character of the Refuges is as diverse as the nation itself. Moosehorn National Wildlife Refuge (MNWR) was established in 1937 as a refuge and breeding ground for migratory birds and other wildlife. It is the first in a chain of migratory bird refuges that extends from Maine to Florida. The Refuge consists of two units. The Baring Unit covers 16,080 acres and is located off U.S. Route 1 southwest of Calais, Maine. The 6,665-acre Edmunds Unit borders the tidal waters of Cobscook Bay near Dennysville, Maine (Figure 1).

### **Objectives**

- 1). To identify ozone-sensitive plant species in the Moosehorn NWR
- 2). To evaluate the incidence and severity of ozone injury on vegetation in the Moosehorn NWR

### **Justification**

Approximately 4,680 acres of the Baring Unit and 2,780 acres of the Edmunds Unit were set aside by Congress as Wilderness Areas, called the Moosehorn Wilderness. In 1978, Moosehorn Wilderness was designated a Class I air quality area, receiving further protection under the Clean Air Act. Congress gave FWS and the other Federal land managers for Class I areas an "...affirmative responsibility to protect all those air quality related values (including visibility) of such lands..." Air quality related values include vegetation, wildlife, water, soils, visibility, and cultural resources. Despite this special protection, many of the resources in these wilderness areas are being impacted or have the potential to be impacted by air pollutants. Because many air pollutants can be carried long distances in the atmosphere, even rural and remote areas are affected by air pollution, including many wilderness areas. To better understand how air pollution affects resources at the Moosehorn NWR, surveys were conducted in 1998 and 1999 to evaluate ozone injury to vegetation within the refuge.

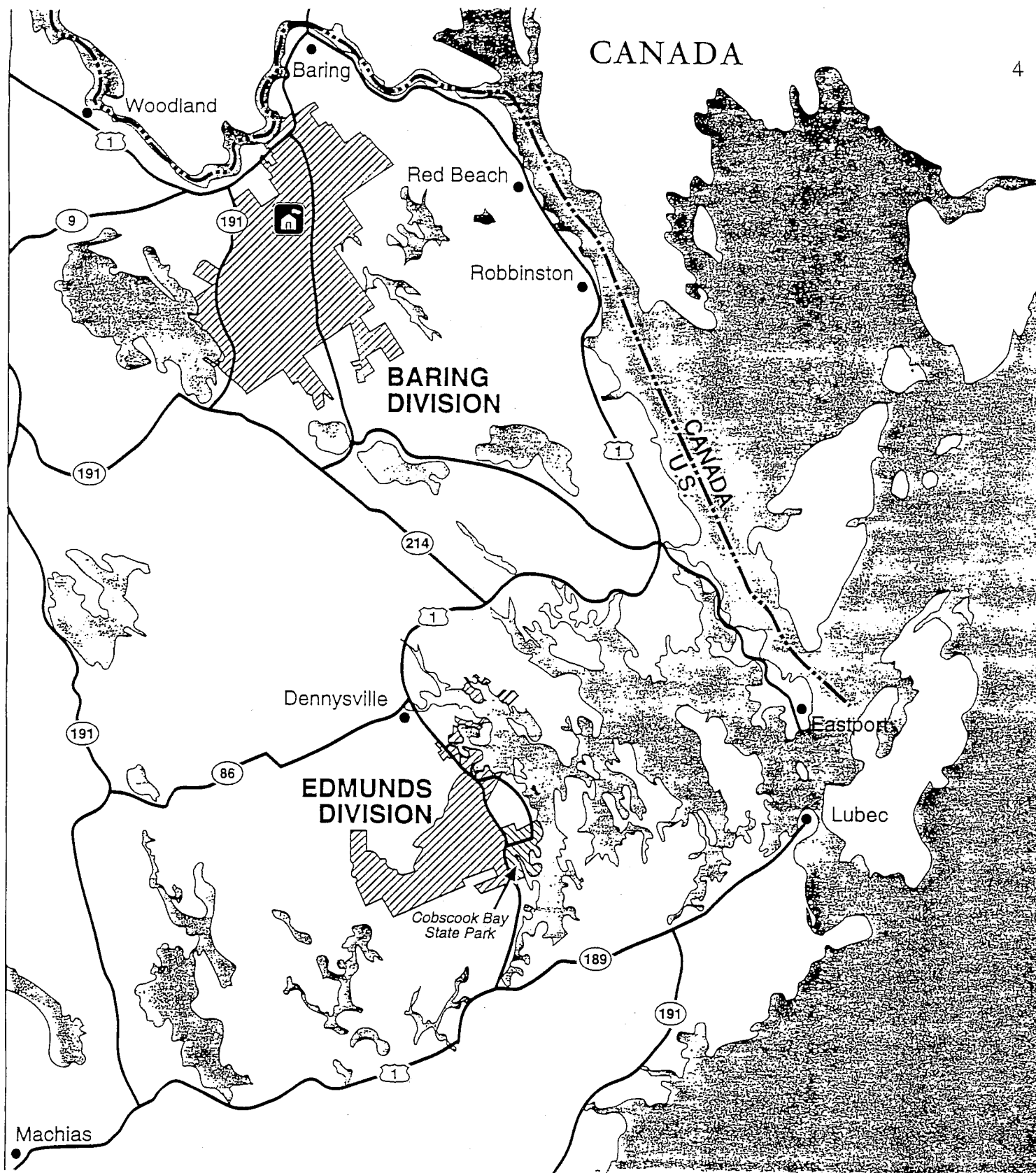


Figure 1. General map of the Moosehead National Wildlife Refuge showing location of Baring Unit and Edmunds Unit. The following two figures show location of survey sites in each Unit.

# BARING

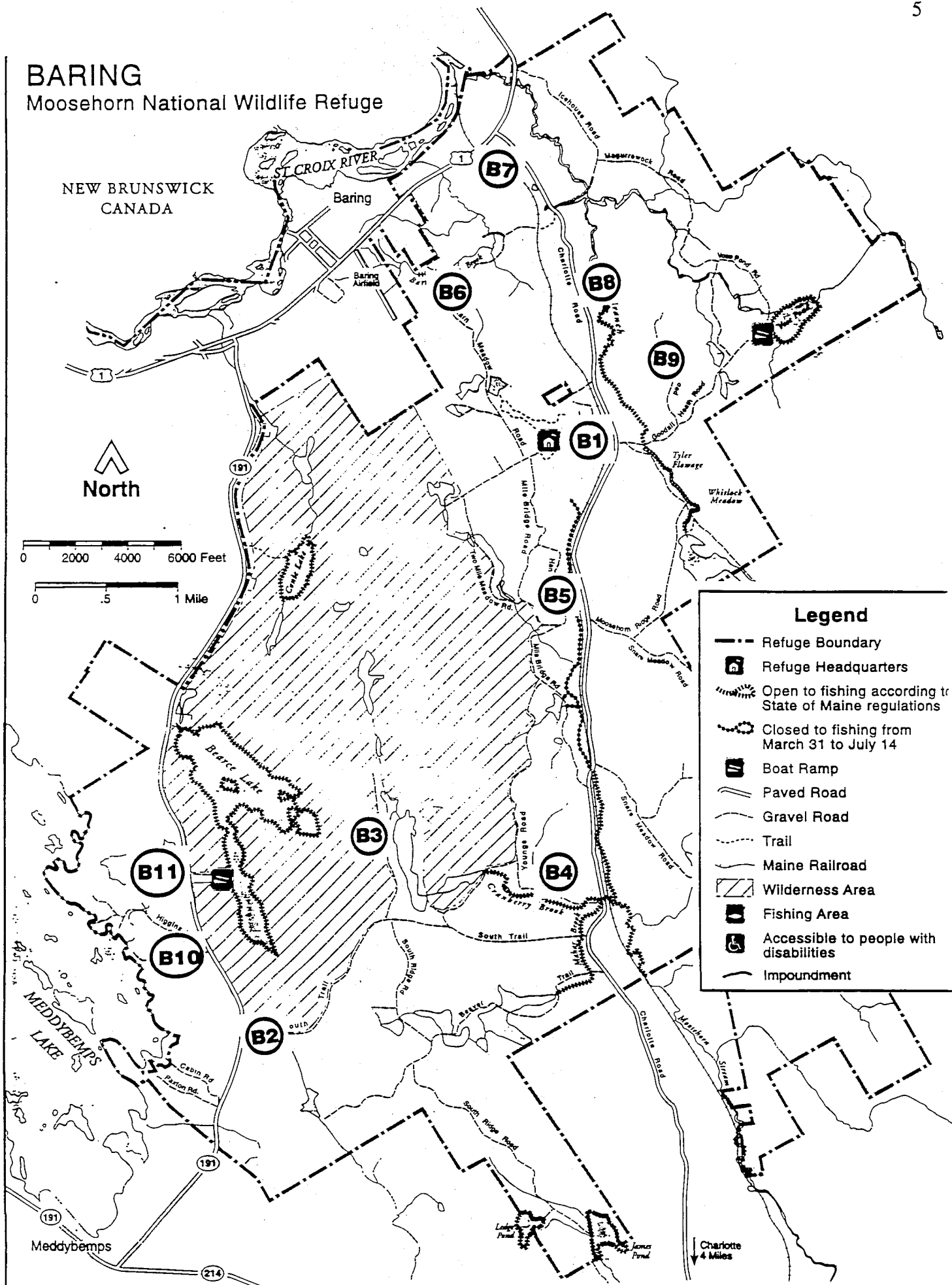
Moosehorn National Wildlife Refuge

NEW BRUNSWICK  
CANADA



0 2000 4000 6000 Feet

0 .5 1 Mile



## Legend

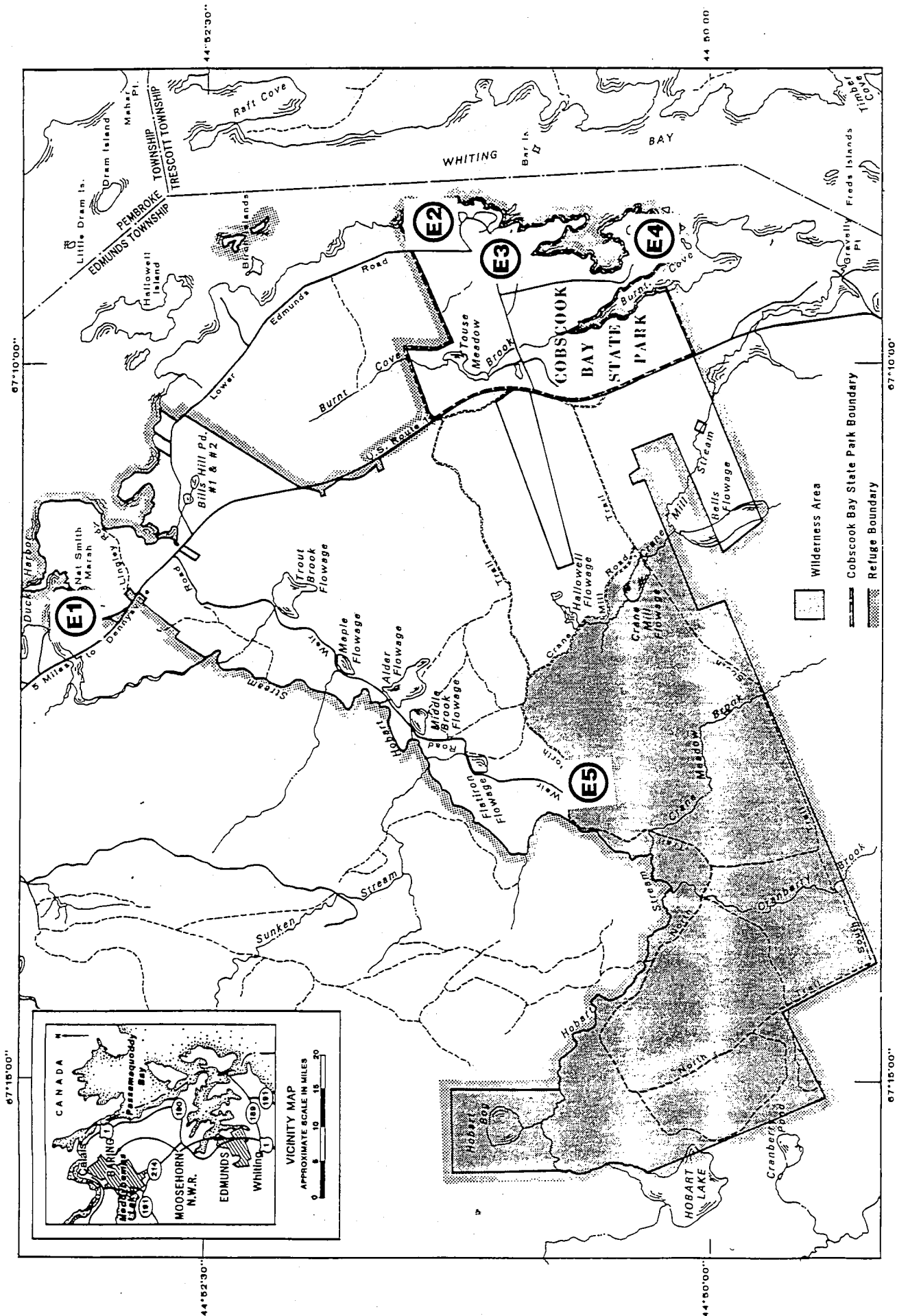
- Refuge Boundary
- Refuge Headquarters
- Open to fishing according to State of Maine regulations
- Closed to fishing from March 31 to July 14
- Boat Ramp
- Paved Road
- Gravel Road
- Trail
- Maine Railroad
- Wilderness Area
- Fishing Area
- Accessible to people with disabilities
- Impoundment

Charlotte  
4 Miles

# MOOSEHORN NATIONAL WILDLIFE REFUGE WASHINGTON COUNTY, MAINE

EDMUNDS UNIT  
UNITED STATES  
FISH AND WILDLIFE SERVICE

UNITED STATES  
DEPARTMENT OF THE INTERIOR



COMPILED IN THE DIVISION OF RECLTY  
FROM SURVEYS BY U.S.G.S. and U.S.F.A.W.S.



### Diagnosis of Air Pollution Injury on Plants

Although many gaseous air pollutants are emitted into the atmosphere, only certain ones are phytotoxic and capable of injuring plants and inducing symptoms readily apparent during field surveys. The most important of these gaseous, phytotoxic air pollutants are ozone, sulfur dioxide ( $\text{SO}_2$ ), and fluorides. These pollutants are taken into the plant leaf, along with the normal constituents of the air, through the stomata. Once inside the leaf, the pollutant or its breakdown products react with cellular components, mainly cellular membranes, causing injury or death of tissues.

The resulting macroscopic symptoms, which are visible on the leaf surface, are classified as chronic or acute depending upon the severity of injury. Chronic symptoms imply tissue injury, whereas acute injury signifies tissue death. Chronic symptoms on foliage usually result from exposure of a plant to low levels of pollution for a long time, or occur when a plant is somewhat resistant to a pollutant. Visible ozone injury is usually considered to be chronic injury. Acute injury is observed following a short-term, high concentration of pollution, or occurs when a plant is in a very sensitive condition. Sulfur dioxide injury as observed in the field is often acute. Fluoride injury may be either.

Macroscopic leaf injury caused by air pollutants often represents an intermediate step between initial physiological events and decreases in productivity. Decreases in productivity (Pye 1988) may result in ecological changes, such as reduced diversity (Rosenberg et al. 1979). Visible leaf symptoms induced by phytotoxic pollutants serve as important diagnostic tools that allow observers to identify specific air pollutants as causal agents of vegetation damage (Davis 1984; Skelly et al. 1987). This knowledge can be used in the air pollution emissions permitting process for siting new industries (i.e. Prevention of Significant Deterioration Program), assessment of the secondary air quality standards, assessing the presence of air pollution injury in Class I areas, and in litigation involving air pollution injury.

Although ozone was the air pollutant of concern in this survey, it should be recognized that phytotoxic levels of  $\text{SO}_2$  and fluorides can occur near industrial sources, and thus are briefly discussed herein. Likewise, heavy metals (which are not discussed in this report) may be found in excessive levels in vegetation growing in areas downwind from industrial or urban sources (Davis et al. 1984). Toxic heavy metals such as mercury may be of importance in areas being managed for wildlife such as a NWR. However, the presence of excessive heavy metals is

determined with laboratory analysis of foliage, not with surveys dealing with macroscopic foliar injury. Also, environmental biohazards such as dioxins and furans may be found downwind of polluted areas. Although such compounds are of more interest in mammalian and avian toxicity as compared to phytotoxicity, vegetation may absorb or adsorb such contaminants and become part of the contaminated food chain. Laboratory analysis of vegetation for dioxins or furans may serve as part of a biomonitoring effort to determine the levels of these biohazards in a given area.

### Ozone

Ozone is probably the most important and widespread phytotoxic air pollutant in the United States, and is the air pollutant most likely to have an easily recognizable impact on vegetation within a NWR. Background levels of ozone exist naturally in the lower atmosphere, possibly originating from vertical downdrafts of ozone from the stratosphere or from lightning, but more likely from chemical reactions of naturally occurring compounds. However, the major sources of precursors leading to phytotoxic levels of ozone occur within urban areas. In those areas, hydrocarbons and oxides of nitrogen are emitted into the atmosphere from various sources, the most important being automobile exhaust. These compounds undergo photochemical reactions in the presence of sunlight forming photochemical smog, of which ozone is a major component. Smog, ozone, or its precursors may travel downwind for hundreds of miles during long-range transport, depending upon wind direction and movement of weather fronts. Thus, the ozone (or its precursors) impinging on refuges may originate in urban areas many miles from the refuge. Concentrations of ozone are often greater in rural areas downwind from urban areas, as compared to within the urban area itself, due to the presence of reactive pollutants in the urban air which scavenge the ozone.

There are certain bioindicator plants that are very sensitive to ozone (Anderson et al. 1989, Davis and Coppolino 1976, Davis and Skelly 1992, Davis et al. 1981, Davis and Wilhour 1976, and Jensen and Dochinger 1989). The principal investigator in this survey routinely uses the following broad-leaved bioindicator species for evaluating ozone injury: black cherry (*Prunus serotina*), common elder (*Sambucus canadensis*), common milkweed (*Asclepias syriaca*), grape (*Vitis* spp), white ash (*Fraxinus americana*), and yellow-poplar (*Liriodendron tulipifera*). The investigator also uses, but less commonly, Virginia creeper (*Parthenocissus quinquefolia*) and

Viburnum spp. Many of these ozone-sensitive species occur in our refuges in eastern United States.

On broadleaved bioindicators, ozone-induced symptoms usually appear as small, 1 to 2 mm diameter "stipples" of pigmented, black or reddish-purple tissue on the adaxial surface of mature leaves (see Skelly et al. 1987). The pigmented tissue is usually restricted by the veinlets. Immature leaves seldom exhibit symptoms, whereas premature defoliation of mature leaves may occur on sensitive species. To the casual observer, these symptoms are similar to those induced by other stresses (e.g., nutrient deficiency, fall coloration, insects, and certain diseases). However, the pigmented, adaxial stipple on plants of known sensitivity (i.e., black cherry or grape) is a reliable diagnostic symptom of ozone injury.

On eastern conifers, the most reliable symptom (current-year needles only) induced by ozone is a chlorotic mottle, which consists of small patches of chlorotic tissue interspersed within the green, healthy needle tissue. The mottle usually has a "soft edge" (as opposed to a sharply defined edge) to the individual mottled areas. An extremely sensitive plant may exhibit needle tip browning. However, this symptom is common to many stresses and not a reliable diagnostic symptom. Conifer needles older than current-year needles are not useful as monitors, since over-wintering may produce symptoms similar to that caused by ozone. Ozone injury to monocots, such as grasses (i.e., Spartina sp.), is very difficult to diagnose in the field, as there are many causal agents that can result in tipburn and chlorotic mottle on grasses. August and early September are the best times to survey for ozone-induced injury in the Northeast (Davis and Skelly 1992).

### Description of Refuge

The Moosehorn Refuge is a highly glaciated expanse of rolling hills, large ledge outcrops, streams, lakes, bogs, and marshes. The Edmunds Unit has several miles of rocky shoreline where 24-foot tidal fluctuations are a daily occurrence. Approximately 2,780 acres of the Edmunds Unit and 4,680 acres of the Baring Unit were set aside as Wilderness Areas by Congress. As part of the National Wilderness Preservation System these areas are granted special protection that will insure the preservation of their wilderness characteristics.

### Vegetation

The area is rich with history from the logging boom days. In the 1800's horses hauled millions of cords of wood to the shores of the St. Croix River where spring floods carried the logs to Calais mills. Logs were shipped from Calais to world markets by schooner and steamship. However, in the early 1900's, the forest industry began to mechanize and the world market for timber declined. The numerous farms that once were necessary to feed man and beast were abandoned and the forest gradually reclaimed the farmland. A diverse forest of aspen, maple, birch, spruce, and fir currently dominates the landscape and scattered stands of majestic white pine are common.

The refuge is located in terrain that consists of rolling hills with large rock outcrops and scattered boulders. The dominant vegetation in the vicinity of both Units is uneven-aged, second-growth northern conifer-hardwood forest, with some areas in pure spruce-fir. Much of the area was logged and cleared in the 1800s and early 1900s, and several fires have burned over large portions of the area, the last in 1933. Numerous stream valleys, beaver flowages, ericaceous bogs, marshes, and forest/shrub-dominated wetlands occur throughout the area. The deciduous component of the forest includes mixed stands of quaking and bigtooth aspen (Populus tremuloides, P. grandidentata), paper and gray birch (Betula papyrifera, B. populifolia), red maple (Acer rubrum), American beech (Fagus grandifolia), and black cherry (Prunus serotina).

Common understory species include winterberry (Gaultheria procumbens), bracken fern (Pteridium aquilinum), sedges (Carex spp.), and bunchberry (Cornus canadensis). Mixed hardwood-conifer stands occur in many areas, with the generally more shade-tolerant conifers gradually replacing the earlier successional hardwoods. The coniferous component is dominated

by mixed and pure stands of spruce (Picea spp.) and balsam fir (Abies balsamea). Scattered old-growth white pine (Pinus strobus) are an indication of the original climax forest that was present before the lumbering and fires of the last century. Pure stands of alder (Alnus rugosa) are abundant in reverting farmland and wet areas along the margins of streams and beaver flowages. Several blueberry (Vaccinium spp.) fields, meadows, and pastures are maintained as permanent forest openings. In 1976, a long-term management plan was implemented on the refuge to increase the diversity of forest habitat by altering age and species composition, utilizing specific timing of cutting.

Wetlands present in the area include beaver ponds and meadows, marsh, shrub, and forested wetlands of various types, and open-water in the form of streams, ponds and lakes. Beaver meadows in the area are dominated by blue-joint grass (Calamagrostis canadensis) and sedges, with wetter sections and pond fringes supporting marsh plants such as rushes (Juncus spp.), cattail (Typha latifolia), bulrushes (Scirpus spp.), and other non-persistent emergents and aquatic species. Alder and willow (Salix spp.) are common wetland shrubs, and leatherleaf (Chamaedaphne calyculata), sweet gale (Myrica gale), and sphagnum moss (Sphagnum spp.) are dominant bog species. Forested wetlands are dominated by stunted spruce, some white cedar (Thuja occidentalis), red maple, sphagnum, cinnamon fern (Osmunda cinnamomea), and some larch (Larix laricina).

The majority of the Cobscook Bay area is in second growth spruce-fir-pine forest, mixed with some maple, birch, and aspen. There is also some open land, and previously-open land in regrowth stages. The waters adjoining the bay are tidal with fluctuations of up to 24 feet, creating extensive areas of intertidal mudflats in several coves. The tidal range and southern exposures create important ice-free and protected wintering habitat conditions for waterfowl and bald eagles. Many large, old-growth pines are present on uplands adjacent to the shoreline, providing nesting and roosting trees for eagles and other raptors.

A listing of Moosehorn NWR vegetation, as supplied by refuge personnel, is presented in the Appendix.

## Wildlife

Moosehorn Refuge is unique among the country's National Wildlife Refuges. Here the American woodcock is intensely studied and managed. This reclusive bird dwells in the alder cover by day and refuge clearings at night. Unfortunately, the Eastern Flyway woodcock population has declined steadily over the past two decades. Research and management programs at Moosehorn have provided valuable information that is being used to stem this decline.

The endangered bald eagle frequents both units of the refuge. In recent years as many as three pairs of eagles have nested at Moosehorn. Eagles are frequently sighted in the area around the Magurrewock Marshes near Route 1 on the Baring Unit and around the tidal waters of Dennys Bay on the Edmunds Unit.

The woodlands of Moosehorn also abound with many other species. Black bears are abundant and can often be seen along refuge roads in the spring, in the blueberry fields in August, and foraging for apples in the fall. White-tailed deer and an occasional moose feed in the many clearings scattered throughout the refuge. In mid-May a flush of migrating warbles fills the woodlands with song.

The refuge also serves as an important breeding area and migration stop for a variety of waterfowl and other waterbirds. Black ducks, wood ducks, ring-necked ducks, Canada geese, and loons can be seen on the over 50 lakes, marshes, and flowages scattered throughout the refuge. In mid-May the Magurrewock Marsh, which borders U. S. Route 1 on the Baring Unit, abounds with goose and duck broods. Bald eagle sightings also are a common occurrence. Ospreys nest in several of the refuge marshes and the ardent observer can often find river otters frolicking among the cattails. Moosehorn plays an important role in protecting the fragile and diminishing wetland resources of the Atlantic Flyway.

## Management

Woodcock, ruffed grouse, moose, deer, and a variety of songbirds will only thrive in a young forest. In the past, wildfires periodically rejuvenated the forest. However, wildfire is a rare event today. Forest management programs on the refuge serve to take the place of fire. Small clearcuts scattered throughout the forest provide openings and young brushy growth that serve as food and cover for many wildlife species. This management has resulted in dramatic increases in many species including woodcock, grouse, bear, and moose. Timber harvesting also provides local employment and a percentage of receipts from sales is returned to local communities.

Wetlands management on the refuge has greatly increased waterfowl numbers. Water control structures on the refuge's marshes and ponds allow managers to maintain stable water levels during the breeding season. Water level control also improves the growth of plants that provide food and cover and allows the marshes to be emptied periodically for rejuvenation. The creation of channels, potholes, and islands, as well as shoreline improvement, has also increased waterfowl production and encouraged nesting.

## METHODS

### General Survey Areas

It had been predetermined that survey sites had to occur in open-areas (such as those occurring along roads or trails, or in fields) where ozone-sensitive plant species were found in sunlight and exposed to unrestricted air movement (Anderson et al. 1989; USDA Forest Service, 1990). Immediately prior to the August 1998 survey, the investigator met with refuge personnel. During this time, maps were viewed and discussed which greatly aided and influenced the preliminary selection of survey areas. Based on these initial discussions, tentative survey areas were selected throughout the refuge during 1998. Each area was visited in 1998 and 1999, its suitability determined, and observations made. These general areas, with slight modification, were used in 2000.

### Preliminary Selection of Bioindicator Species

An extensive list of refuge flora was furnished to the investigator by the U.S. Fish and Wildlife Service (Appendix). Prior to the initial (1998) survey, an initial selection of potential bioindicators that might exhibit ozone injury in the survey area had been selected from this list, as well as by talking to refuge personnel. Plant species or genera on the list that were tentatively selected as bioindicators included: ash (Fraxinus sp.), aster (Aster sp.), black cherry (Prunus serotina), blackberry (Rubus sp.), choke cherry (Prunus virginiana), common milkweed (Asclepias syriaca), elderberry (Sambucus canadensis), mountain ash (Sorbus americana), pin cherry (Prunus pensylvanica), poison-ivy (Rhus radicans = Toxicodendron radicans), serviceberry (Amelanchier laevis), sumac (Rhus sp.), trembling aspen (Populus tremuloides) and viburnum (Viburnum sp.).

Of course, many of the species listed grow in scattered localities through the NWR, and may not be present at designated survey areas; they may only be found with the help of local botanists. Also, it should be pointed out that most plant species growing in the more wet areas of the refuge have not been studied with regard to ozone-induced macroscopic symptoms. That is, the ozone-sensitivity of wetland species, as determined by controlled exposures of ozone, is generally unknown.



### Air Quality

Ozone monitoring data are useful to complement the visual injury surveys. In general, more ozone-induced stipple is likely to occur in years with greater ozone concentrations. However, more consistent and long-term monitoring datasets are needed to further understand the relationship between foliar symptoms, ambient ozone, and environmental conditions (e.g. droughts) in our parks and refuges.

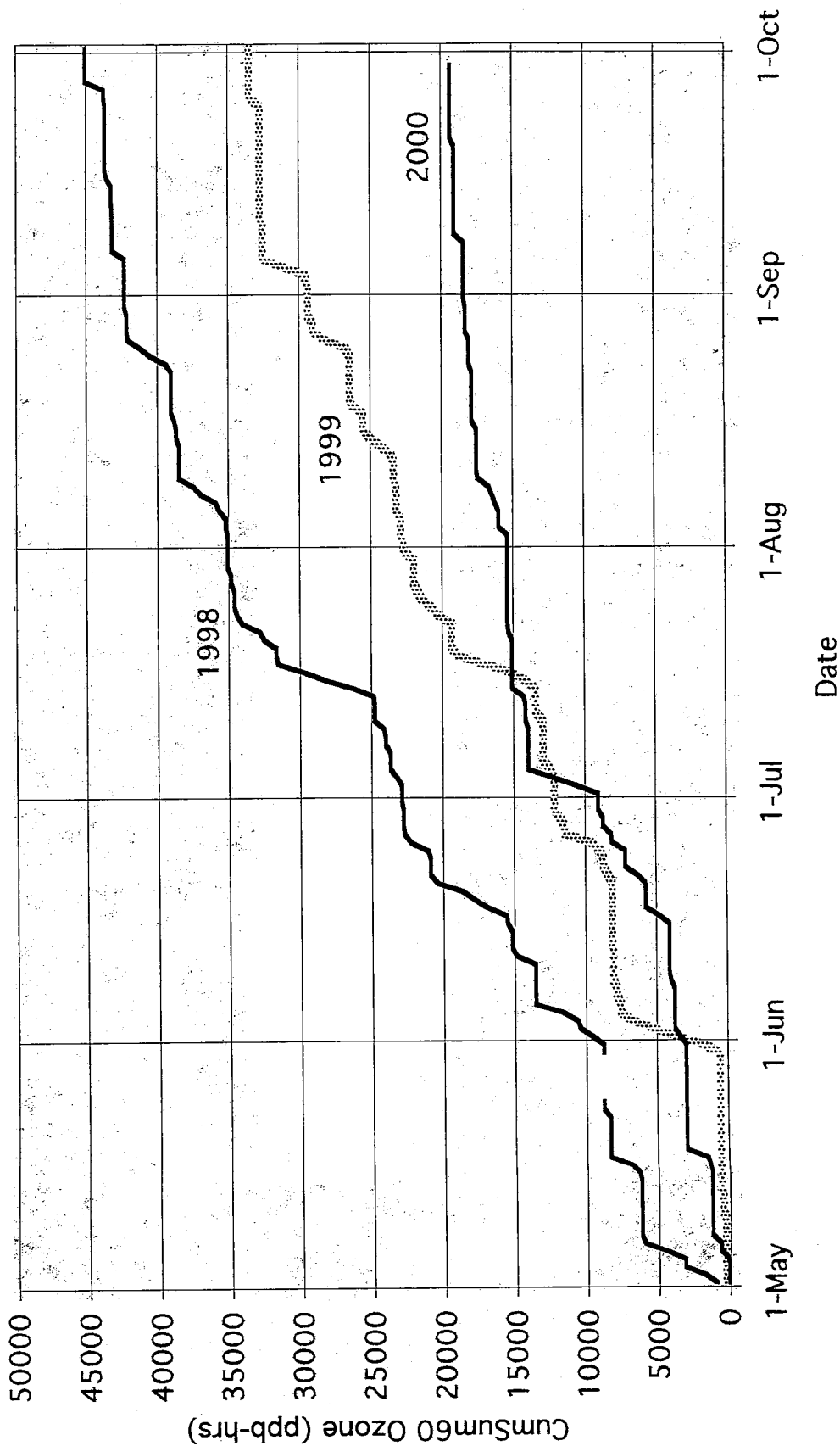
The nearest ozone monitor with the complete ozone datasets is in Acadia National Park at Cadillac Mountain (EPA AIRS site #23-009-0102), located approximately 70 miles southwest of the Moosehorn NWR. Ambient ozone levels in this report are expressed as "cumSUM60", the cumulative sum of all hourly ozone concentrations equaling or exceeding 60 ppb. In other studies, we have found that this ozone statistic correlates fairly well with plant damage. During the 3 most recent years (1998-2000) of monitoring at Cadillac Mountain, ozone levels were greatest in 1998, intermediate in 1999, and very low in 2000 (Figure 2). By late summer, the cumSUM60 ozone levels in 1998 were clearly at phytotoxic levels, and the 1999 levels were considered to be somewhat phytotoxic. In 2000, the ozone levels were very low and were just at the threshold limits for plant injury to occur (approximately 20,000 ppb-hrs).

During the last 3 years, the maximum cumSUM60 values peaked at approximately 45,000 ppb-hrs, which occurred in 1998. For comparison to a refuge with extreme ozone concentrations, the ozone levels at the Edwin B. Forsythe NWR near Brigantine, New Jersey, reached about 80,000 ppb-hrs in 1991 (a very high ozone year), and are routinely greater than 40,000 ppb-hrs by the summer's end. During 1999, ozone levels in the Mingo NWR in Missouri likewise reached 80,000 ppb-hrs by early fall.

Assuming that the ozone levels monitored at Cadillac Mountain (70 miles away) are similar to those occurring at the Moosehorn NWR, ozone injury is likely to occur most years on ozone-sensitive species of vegetation within the refuge. However, to my knowledge, there have been no recorded surveys prior to 1998 to document whether or not ozone injury has occurred on refuge vegetation.

Figure 2. Cumulative sum of all hourly ozone concentrations equaling or exceeding 60 ppb (cumSUM60) monitored at Acadia National Park, Cadillac Mountain, Maine (EPA AIRS Site # 23-009-0102) during 1998-2000; units are ppb-hrs. This monitoring site is located approximately 70 miles southwest of the Moosehorn refuge.

Ozone Levels at Acadia, ME  
(EPA AIRS Site # 23-009-0102)



### Surveys Dates and Areas

The Moosehorn National Wildlife Refuge was surveyed twice in 1998, on July 29-August 2 and August 25-28. In 1999 the refuge was surveyed once, during July 22-25. It was fortunate that the earlier date was chosen in 1999, because a widespread drought occurred in the East during late summer. During 2000, the Moosehorn NWR was surveyed during August 21-23. (Based on the 3 years of surveys, the best time to survey this refuge is in mid- to late-August.

As described earlier, the tentative location of survey areas was based on discussions with refuge personnel and examination of maps at the refuge headquarters prior to the initial (1998) survey. These areas were then visited on-site during the 1998 and 1999 surveys, and 16 approximately sites were selected. These sites were considered suitable for ozone injury surveys based on openness, accessibility, and presence of bioindicators (Figure 1). All 16 sites were visited in 2000, but data was not taken at all sites. However, an additional area ("The Woodcock Trail") adjacent to plot B1 was added to in 2000. In addition to these specific areas, vegetation was observed as the investigator traveled from site to site.

### Severity Rating

Each broadleaved plant evaluated for ambient ozone injury had to have foliage within reach; that is, trees were not climbed nor were pole-pruners used. The ForestHealth Expert System had been used to train the investigator in estimating the amount of stipple on a leaf. For broadleaved tree species, the percentage of ozone injury was estimated on the oldest leaf on each of four branches, and the average value recorded. Then, the next oldest leaf was evaluated, and so on, until the five oldest leaves had been rated. For each herbaceous plant, each of the five (if present) oldest (basal) leaves of the plant was examined and the average percent stipple recorded. Each of the oldest five leaves on the current woody growth (canes) of vines was rated and the average percent stipple recorded. On all species, only adaxial leaf surfaces were evaluated. Symptom severity on the adaxial surface of each leaf evaluated was estimated by assigning severity classes, based on the percentage of surface injured, of 0, 5, 10, 20, 40, 60, 80, 90, 95 and 100 %. Photographs (slides) were taken and originals sent to the FWS Air Quality Branch in Denver.

## RESULTS AND DISCUSSION

### Final Selection of Bioindicator Species

Following the initial evaluation of the vegetation lists in early summer 1998, a more complete selection of bioindicator species or genera was made in the field during 1998. For example, during the first 1998 visit to the refuge, it was immediately obvious that spreading dogbane (Apocynum androsaemifolium) was exhibiting adaxial stipple, typical of that caused by ozone, at several sites. Therefore, dogbane was added to the bioindicator list, which then consisted of ash (mainly white ash), black cherry, blackberry, choke cherry, pin cherry, serviceberry, and trembling aspen as potential bioindicator species. These were among the most common of the ozone-sensitive species in the refuge, and usually occurred in open areas. Not all species/genera listed were present at all sites. In addition, most wetland plant species of the Moosehorn refuge have not been carefully studied with regard to ozone-induced macroscopic symptoms. That is, the ozone-sensitivity of wetland plants as determined by controlled exposures of ozone is generally unknown.

During the 1998 and 1999 field surveys, the bioindicator list was amended to also include sand cherry (Prunus pumila), raspberry (Rubus idaeus), and sarsaparilla (Aralia nudicaulis). The latter two species, along with blackberry, were selected as indicators for SO<sub>2</sub> injury. However, since there was no point source of SO<sub>2</sub> readily evident, emphasis was placed on the ozone-sensitive bioindicators. The list as compiled by the end of 1999 was used during the 2000 survey.

## Foliar Symptoms

In spite of the low ozone levels recorded in 2000 (Figure 2), ozone-induced injury was observed at several sites within both the Baring and Edmunds Units during the 2000 visit (August 21-23). Apparently environmental conditions were ideal for development of ozone-induced symptoms. And, the time of survey appeared to be ideal for detecting ozone injury.

### Baring Unit

**Site B1 (Refuge Headquarters and "Woodcock Trail").** Vegetation was examined in the large, open fields along the entrance road leading to the refuge headquarters and along the 1/3 mile Woodcock Trail loop (Figure 1, Location B1). There were several bioindicator "species" present in these large openings and along the trail at this excellent survey site.

Ozone injury was light in incidence, and light to moderate in severity, on spreading dogbane plants, where injury was present on 20 of 70 (28.6%) plants examined (Table 1). The incidence of ozone-induced injury was greater in 2000 than in 1998 or 1999. Also, in 1998 and 1999 the ozone injury on dogbane had been restricted to older paired leaves on the primary stems, and did not occur on the pairs of leaves further out the secondary shoots. (Secondary shoots arose from the axil of these pairs of primary stem leaves). However, in 2000 the ozone injury also occurred on the leaves further out the stem in addition to the two older paired leaves. The severity of injury on the symptomatic leaves was judged to be light to moderate in 2000, usually involving less than 5% of the adaxial leaf area, but at times involving up to 40% of the leaf surface (Table 2).

Near the upper edge of one field, brush and grass had been mowed the previous year and very succulent aspen sprouts (and root suckers) were present. This site had not been mowed in 1998 and there were no sprouts available for rating. Ozone injury was present on 10 of 24 (41.7%) of these aspen sprouts in 2000 (Table 1); injury was restricted to the fast-growing sprouts, and did not occur on the larger trees or older saplings. The severity of ozone injury was judged to be light (Table 2). In 1999 ozone injury had occurred on 6 of 58 (10.3%) of the same groups of aspen sprouts.

Table 1. Summary of observations made during the 2000 survey at the Moosehorn National Wildlife Refuge. Numbers in table refer to number of plants with ozone-induced injury as compared to the total number of plants evaluated for that species, and expressed as percentages. Comparison is made with the 1999 and August 1998 results.

Date/Site	Aspen		Black-		Cherry			Dogbane		Mtn-		Rasp-		Sarsap-		Service-	
	Ash	Trem.	Bigth.	berry	Black	Choke	Pin	Sand	Spreading	Ash	berry	berry	arilla	berry	Viburnum		
August 98 Total	1/54	10/126		0/53	0/55	0/30	28/108		7/77								
Aug 98%	1.8%	7.9%		0.0%	0.0%	0.0%	25.9%		9.0%								
1999 Total	2/77	9/396		0/330	5/111	0/260	4/196	0/40	10/178	0/10	0/230	0/10	0/10	1/49			
1999%	2.6%	2.3%		0.0%	4.5%	0.0%	2.0%	0.0%	5.6%	0.0%	0.0%	0.0%	0.0%	2.0%			
2000																	
Baring Unit																	
B1		10/24	0/10	0/30	0/10	0/20	0/10	0/10	20/70					0/2		2/10	
B2	5/55																
B3	0/20	0/20															
B4	0/2	0/10			0/30		0/20		0/20								
B5		2/50					0/10		2/20								
B6																	
B7																	
B8	0/9			0/10							0/10			0/2			
B9	1/30	0/10	0/10	0/30	0/20	0/20			2/10		0/50	0/30		0/10			
B10																	
B11	0/30																
Edmunds Unit																	
E1		0/20		0/30				0/40			0/20			0/20			
E2																	
E2a					0/26		0/13			0/10							
E3		0/20		0/100		0/20					0/100			1/6			
E4							11/100										
E5	0/4						3/23										
2000 Total	6/150	12/154	0/20	0/200	0/86	0/60	13/176	0/50	24/120	0/10	0/180	0/30	0/30	1/40	2/10		
2000%	4.0%	7.8%	0.0%	0.0%	0.0%	0.0%	7.4%	0.0%	20.0%	0.0%	0.0%	0.0%	0.0%	2.5%	20.0%		



Table 2. Severity of ozone-induced injury on leaves of symptomatic leaves of aspen and spreading dogbane at Site B1.

Species	Plant No.	Leaf No.				
		1*	2	3	4	5
<u>Aspen</u>	1	40	20	10	5	0
	2	20	20	20	0	0
	3	40	20	0	0	0
	4	30	10	0	0	0
	5	30	20	5	0	0
	6	40	20	5	0	0
	7	10	10	0	0	0
	8	10	5	0	0	0
	9	5	0	0	0	0
	10	20	10	0	0	0
<u>Dogbane</u>	1	20	20	10	0	0
	2	5	5	0	0	0
	3	10	5	0	0	0
	4	40	20	0	0	0
	5	20	10	0	0	0
	6	40	30	0	0	0
	7	5	5	5	0	0
	8	10	0	0	0	0
	9	40	20	0	0	0
	10	30	10	0	0	0
	11	10	0	0	0	0
	12	40	10	0	0	0
	13	40	20	0	0	0
	14	10	0	0	0	0
	15	5	0	0	0	0
	16	5	5	0	0	0
	17	20	10	0	0	0
	18	40	20	0	0	0
	19	5	0	0	0	0
	20	10	0	0	0	0

\*Oldest leaf of the 5 leaves evaluated.

\*\*Severity values = 0, 5, 10, 20, 40, 60, 80, 90, 95, and 100% of leaf tissue injured.

Along the Woodcock Trail, classic ozone-induced stipple was observed on two plants tentatively identified as Viburnum lentago. The investigator has observed ozone stipple on various species of Viburnum in other surveys, and considers the genus Viburnum to be an under-used bioindicator with excellent potential, perhaps similar in utility to the genus Sambucus. This species of Viburnum could prove to be a valuable addition to the bioindicators already used for detecting ozone injury in the refuge. The species exhibits symptoms that are more classic stipple, as compared to ash or pin cherry, and does not defoliate as readily as spreading dogbane. In the future, consideration should be given to more thorough ozone-injury survey using this species.

Ozone injury was not observed on bigtooth aspen, blackberry, black cherry, choke cherry, sand cherry, or mountain-ash. Although choke cherry was evaluated, the investigator considers this species to be tolerant to ambient levels of ozone and it may not be evaluated in the future. There was a slight reddening, which may or may not have been related to ozone injury, on blackberry. Leafspots were severe on black cherry, dogbane, pin cherry, quaking aspen (also tip dieback), and others. Black and sand cherry had black knot galls on the branches, and black cherry also had spindle galls on the leaves. Fall webworm, skeletonizers, chewing insects, and other insect disorders were common. These various diseases and disorders are described here, but were common at most sites. During the 2000 survey, injury resembling that caused by SO<sub>2</sub> was not observed on any plants at any sites.

**Sites B2-B11 (see Table 1).** At site B2 (western end of South Trail) 5 of 55 (9.1%) of the ash seedlings and saplings examined showed classic ozone injury. At site B3 (Cranberry Lake Inlet) none of the 20 ash nor 20 aspen had ozone injury. Ash, aspen, black cherry, dogbane, and pin cherry plants at site B4 (Cranberry Brook) likewise showed a lack of ozone injury. At site B5 (Hanson Soil Pit Road), pin cherry showed no ozone injury, and many of the aspen sprouts were stressed by a fungal leaf and shoot blight, likely caused by the fungus Venturia, as in 1999. Most plants were not evaluated at site B5 because of this confounding factor. However, several adjacent clearcuts were found that had few fungal diseases on the aspens. In these areas, 2 of 50 aspens had ozone injury. Two of 20 dogbane plants also exhibited classic ozone injury. Few good indicator plants were found at sites B6 (Barn Meadows #2) and B7 (Powerline at the intersection of Route 1 and Charlotte Road), and these two sites

may be eliminated. Site B8 (West Branch Observation Deck) is also marginal site in terms of usefulness, but is better than B6 and B7; ozone injury was not observed on any plants at site B8. Site B9 (road to former air monitoring station) was expanded in 1999 to include Voss Pond and is now an excellent site. Ozone injury was recorded on 1 of 30 ash, and 2 of 10 spreading dogbane plants at site B9. Ozone injury was not observed on aspen, black cherry, blackberry, or serviceberry at this site. Moderate levels of Venturia shoot blight occurred on aspen at this site and throughout the area. There was no ozone injury on 30 ash seedlings and saplings examined at site B11 (Bearce Flowage)

Sites B6, B7, B10 (Higgins Road) and B11 (Bearce Flowage) are considered to be marginal survey sites. However, all four sites will be maintained, and possibly revisited if the survey is conducted in future years.

### **Edmunds Unit**

**Site E1.** Vegetation was examined in 2000 in and around the edges of the farm fields near the Nate Smith Marsh. As in 1998 and 1999, there were several bioindicators present in these large fields. Ozone injury was not observed on aspen, blackberry, sand cherry, or serviceberry. Raspberry plants had healthy leaves at this site. Black knot disease was very severe on various Prunus species at this location.

**Site E2.** Ozone injury was not observed on black cherry, pin cherry, or mountain-ash plants near the boat launch in Cobscook State Park (Table 1). Raspberry plants also had healthy leaves at this site. There was no ozone injury on any bioindicators examined (Table 1). As in 1999, mountain-ash trees had severe leafhopper-type injury, which confounded ozone injury evaluations on this species. Here and elsewhere in the area, there was no SO<sub>2</sub> injury on birch, raspberry, blackberry, nor sarsaparilla.

**Site E3.** Bioindicators were examined in and around the edge of this very large field within the Cobscook State Park, located near the edge of Whiting Bay. In 1999, ozone injury had been noted on 5 of 26 (19.2%) of the black cherry and 3 of 13 (23.1%) of the pin cherry plants examined. In 2000, the only ozone injury was noted on 1 of 6 serviceberry trees. Raspberry plants had healthy leaves.

**Site E4.** Vegetation was examined in this very large field near the south end of Cobscook State Park. There was a large clump of pin cherry saplings in the field. These plants

were possibly from the same seed source, or sprouts, since they were growing close together. In 1998 19 of 40 (47.5%) pin cherries in this clump examined exhibited ozone injury. However, the clump had been cut in 1999, and stumps were just beginning to sprout at the time of that year's survey. A total of 67 new sprouts were examined in 1999, but ozone injury was not observed (Table 1). In 2000, ozone injury was noted on 11 of 100 (11.0%) pin cherry trees. It is likely that the pin cherry leaves were not mature enough in 1999 to exhibit ozone injury, or they were so new that they had not been exposed to sufficient levels of ozone to cause injury. Apparently, ambient ozone levels were not high enough in 2000 to cause as much injury as in 1998.

**Site E5.** Of the 23 pin cherries examined near the intersection of North Trail and Weir Road, three plants exhibited ozone injury.

## SUMMARY

The results of this 2000 survey revealed that ozone injury was present on vegetation within the boundaries of the Moosehorn NWR, a portion of which is a Class I air quality area. In 1998 (August), ozone-induced foliar symptoms were fairly high, and were related to the high levels of ambient ozone that year (Figure 2). The 1999 ambient ozone levels were lower than in 1998, and 1999 was a dry year. The drought symptoms as observed in 1999 were widespread, and included plant yellowing, wilting, curling and defoliation. It is very likely that the dry weather of 1999 precluded ozone uptake by plants, and reduced subsequent symptom development in that year. The ozone levels of 2000 were very low, but moisture conditions during the survey appeared adequate. There was no observed wilting of plants due to drought stress during the 2000 surveys. Thus, in spite of the low ambient ozone concentrations, ozone-induced injury did occur in the summer of 2000 within the refuge.

These results should prove useful to the FWS when making air quality management decisions, including those related to the review of Prevention of Significant Deterioration (PSD) permits.

## RELATED LITERATURE

- Anderson, R. L., C. M. Huber, R. P. Belanger, J. Knighten, T. McCartney, and B. Book. 1989. Recommended survey procedures for assessing on bioindicator plants in Region 8 Class 1 Wilderness areas. USDA Forest Service, Forest Pest Management, Asheville Field Office Report 89-1-36, 6 pp.
- Conkling, B. L. and G. E. Byers (eds.). 1993. Forest Health Monitoring Field Methods Guide. Internal Report. US EPA, Las Vegas, NV
- Davis, D. D. 1984. Description of leaf injury caused by gaseous air pollutants. pp 77-82 In: Davis, et al. (ed.). Proc. Sym. Air Pollut. and Productivity of the Forest, Wash., DC. Oct. 4-5, 1983. Pub. by Izaak Walton League, Wash., DC, 344 pp. .
- Davis, D. D. and J. B. Coppelino. 1976. Ozone susceptibility of selected woody shrubs and vines. Plant Dis. Rptr. 60:876-878.
- Davis, D. D., A. Millen, and L. Dochinger (ed.). 1984. Air pollution and productivity of the forest. Proc. Sym. Air Pollut. and Productivity of the Forest, Wash., DC. Oct. 4-5, 1983. Pub. by Izaak Walton League, Wash., DC, 344 pp.
- Davis, D. D., J. M. Skelly, and B. L. Nash. 1995. Major and trace element concentrations in red oak, white oak, and red maple foliage across an atmospheric deposition gradient in Pennsylvania. Proc. Tenth Annual Centr. Hdwd. Conf. Morgantown, WVA, USDA Forest Service Tech. Bull. pp 188-195.
- Davis, D. D. and J. M. Skelly. 1992. Foliar sensitivity of eight eastern hardwood tree species to ozone. J. Water, Air, Soil Pollut. 62:269-277.
- Davis, D. D., D. M. Umbach, and J. B. Coppelino. 1981. Susceptibility of tree and shrub species and response of black cherry foliage to ozone. Plant Dis. 65: 904-907.
- Davis, D. D. and R. G. Willhour. 1976. Susceptibility of woody plants to sulfur dioxide and photochemical oxidants. E.P.A. Ecol. Res. Series EPA 600/3-76-102, 70 pp.
- Davis, D. D., F. A. Wood, R. J. Hutnik, G. C. Weidersum, and W. R. Rossman. 1984. Observations around coal-fired power plants in Pennsylvania. Forest Wissen. Centralblatt 103:61-73.
- Jensen, K. F. and L. S. Dochinger. 1989. Response of eastern hardwood species to ozone, sulfur dioxide, and acidic precipitation. J. Air Pollut. Control Assoc. 39:852.
- Pye, J. M. 1988. Impact of ozone on the growth and yield of trees: A review. J. Environ. Qual. 17:347-360.

- Rosenberg, C. R., R. J. Hutnik, and D. D. Davis. 1979. Forest composition at varying distances from a coal-burning power plant. *Environ. Pollut.* 19:307-317.
- Skelly, J. M., D. D. Davis, W. Merrill, and E. A. Cameron. (Eds.). 1987. Diagnosing injury to eastern forest trees. College of Agric., Penn State Univ., 122 pp.
- Umbach, D. M. and D. D. Davis. 1984. Severity and frequency of SO<sub>2</sub>-induced leaf necrosis on seedlings of 57 tree species. *For. Sci.* 30:587-596.
- van Haut, H. and H. Stratmann. 1969. Color-plate atlas of the effects of sulfur dioxide on plants. Verlag W. Girardet, Essen, W. Germany, 206 pp.
- Wood, F. A., R. J. Hutnik, D. D. Davis, G. C. Weidersum, and W. R. Rossman. 1982. Effects of large coal-burning power plants on vegetation in western Pennsylvania. Pres. 75th Annu. Meet. APCA, New Orleans, Preprint No. 82-67.7.

## Appendix – Vegetation at Moosehorn NWR

*Abies balsamea* (balsam fir)  
*Acer pensylvanicum* (striped maple)  
*Acer rubrum* (red maple)  
*Acer saccharum* (sugar maple)  
*Acer spicatum* (mountain maple)  
*Achillea millefolium* (common yarrow)  
*Actaea rubra* (red baneberry)  
*Agropyron repens* (*Elytrigia repens* var. *repens*)  
*Agrostis alba* (*Agrostis gigantea*)  
*Alisma subcordatum* (American water plantain)  
*Alnus crispa* (*Alnus viridis* ssp. *crispa*)  
*Alnus rugosa* (*Alnus incana* ssp. *rugosa*)  
*Alopecurus pratensis* (meadow foxtail)  
*Amelanchier laevis* (Allegheny serviceberry)  
*Anaphalis margaritacea* (western pearly everlasting)  
*Andromeda glaucophylla* (*Andromeda polifolia* var. *glaucophylla*)  
*Antennaria neodioica* (*Antennaria howellii* ssp. *neodioica*)  
*Anthoxanthum odoratum* (sweet vernalgrass)  
*Apocynum androsaemifolium* (spreading dogbane)  
*Aquilegia vulgaris* (European columbine)  
*Aralia hispida* (bristly sarsaparilla)  
*Aralia nudicaulis* (wild sarsaparilla)  
*Arctium minus* (lesser burdock)  
*Arisaema atrorubens* (*Arisaema triphyllum* ssp. *triphyllum*)  
*Asclepias incarnata* (swamp milkweed)  
*Asclepias syriaca* (common milkweed)  
*Aster acuminatus* (whorled wood aster)  
*Aster macrophyllus* (bigleaf aster)  
*Aster radula* (low rough aster)  
*Aster umbellatus* (parasol aster)  
*Aster undulatus* (waxy leaf aster)  
*Athyrium filix-femina* (common ladyfern)  
*Barbarea vulgaris* (garden yellowrocket)  
*Berberis thunbergii* (Japanese barberry)  
*Betula papyrifera* (paper birch)  
*Betula populifolia* (gray birch)  
*Brassica juncea* (India mustard)  
*Calamagrostis canadensis* (bluejoint)  
*Capsella bursa-pastoris* (shepherd's purse)  
*Carex crinita* (fringed sedge)  
*Carex intumescens* (greater bladder sedge)  
*Carex stricta* (upright sedge)



*Carex trisperma* (threeseeded sedge)  
*Carum carvi* (caraway)  
*Cerastium vulgatum* (*Cerastium fontanum* ssp. *vulgare*)  
*Chamaedaphne calyculata* (leatherleaf)  
*Chelone glabra* (white turtlehead)  
*Chimaphila umbellata* (pipsissewa)  
*Chrysanthemum leucanthemum* (*Leucanthemum vulgare*)  
*Circaea alpina* (small enchanter's nightshade)  
*Cirsium arvense* (Canadian thistle)  
*Cirsium discolor* (field thistle)  
*Cirsium vulgare* (bull thistle)  
*Clematis virginiana* (devil's darning needles)  
*Clintonia borealis* (yellow bluebeadlily)  
*Comptonia peregrina* (sweet fern)  
*Coptis groenlandica* (*Coptis trifolia* ssp. *groenlandica*)  
*Cornus alternifolia* (alternateleaf dogwood)  
*Cornus canadensis* (bunchberry dogwood)  
*Cornus stolonifera* (*Cornus sericea* ssp. *sericea*)  
*Coronilla varia* (purple crownvetch)  
*Corylus cornuta* (beaked hazelnut)  
*Crassula aquatica* (water pygmyweed)  
*Cycloloma atriplicifolium* (winged pigweed)  
*Cypripedium acaule* (pink lady's slipper)  
*Cypripedium calceolus* ()  
*Dactylis glomerata* (orchardgrass)  
*Dalibarda repens* (robin runaway)  
*Danthonia spicata* (poverty danthonia)  
*Dennstaedtia punctilobula* (eastern hayscented fern)  
*Deschampsia flexuosa* (wavy hairgrass)  
*Dianthus armeria* (Deptford pink)  
*Diervilla lonicera* (northern bush honeysuckle)  
*Distichlis spicata* (inland saltgrass)  
*Dryopteris cristata* (crested woodfern)  
*Dryopteris disjuncta* (*Gymnocarpium disjunctum*)  
*Dryopteris marginalis* (marginal woodfern)  
*Dryopteris noveboracensis* (*Thelypteris noveboracensis*)  
*Dryopteris phegopteris* (*Phegopteris connectilis*)  
*Dryopteris spinulosa* (*Dryopteris carthusiana*)  
*Dryopteris thelypteris* (*Thelypteris palustris* var. *pubescens*)  
*Dulichium arundinaceum* (threeway sedge)  
*Epigaea repens* (trailing arbutus)  
*Epilobium angustifolium* (fireweed)  
*Equisetum arvense* (field horsetail)  
*Equisetum fluviatile* (water horsetail)  
*Equisetum hyemale* (scouringrush horsetail)  
*Equisetum sylvaticum* (woodland horsetail)

*Erigeron annuus* (eastern daisy fleabane)  
*Erigeron strigosus* (prairie fleabane)  
*Eriocaulon septangulare* (*Eriocaulon aquaticum*)  
*Eriophorum angustifolium* (tall cottongrass)  
*Eriophorum spissum* (*Eriophorum vaginatum* var. *spissum*)  
*Eupatoriadelphus purpureus* (*Eupatorium purpureum* var. *purpureum*)  
*Eupatorium maculatum* (spotted joeypyeweed)  
*Euthamia graminifolia* (flattop goldentop)  
*Fagus grandifolia* (American beech)  
*Festuca capillata* (*Festuca filiformis*)  
*Festuca elatior* (*Festuca pratensis*)  
*Festuca rubra* (red fescue)  
*Fragaria virginiana* (Virginia strawberry)  
*Fraxinus americana* (white ash)  
*Fraxinus pennsylvanica* (green ash)  
*Galeopsis tetrahit* (brittlestem hempnettle)  
*Galium mollugo* (false baby's breath)  
*Galium palustre* (common marsh bedstraw)  
*Galium triflorum* (fragrant bedstraw)  
*Gaultheria hispidula* (creeping snowberry)  
*Gaultheria procumbens* (eastern teaberry)  
*Gaylussacia baccata* (black huckleberry)  
*Gaylussacia dumosa* (dwarf huckleberry)  
*Geranium bicknellii* (Bicknell's cranesbill)  
*Glyceria canadensis* (rattlesnake mannagrass)  
*Glyceria obtusa* (Atlantic mannagrass)  
*Hamamelis virginiana* (American witchhazel)  
*Hemerocallis fulva* (orange daylily)  
*Hieracium aurantiacum* (orange hawkweed)  
*Hieracium florentinum* (*Hieracium piloselloides*)  
*Hieracium pilosella* (mouseear hawkweed)  
*Hieracium pratense* (*Hieracium caespitosum*)  
*Hordeum californicum* (California barley)  
*Humulus lupulus* (common hop)  
*Hypericum ellipticum* (pale St. Johnswort)  
*Hypericum perforatum* (common St. Johnswort)  
*Ilex verticillata* (common winterberry)  
*Impatiens capensis* (jewelweed)  
*Iris versicolor* (harlequin blueflag)  
*Juniperus communis* (common juniper)  
*Kalmia angustifolia* (sheep laurel)  
*Kalmia polifolia* (bog laurel)  
*Larix laricina* (tamarack)  
*Ledum groenlandicum* (bog Labrador tea)  
*Lilium canadense* (Canadian lily)  
*Linaria canadensis* (*Nuttallanthus canadensis*)

*Linaria vulgaris* (butter and eggs)  
*Linnaea borealis* (twinline)  
*Lobelia cardinalis* (cardinalflower)  
*Lobelia dortmanna* (Dortmann's cardinalflower)  
*Lonicera canadensis* (American fly honeysuckle)  
*Ludwigia palustris* (marsh seedbox)  
*Luzula acuminata* (hairy woodrush)  
*Luzula multiflora* (common woodrush)  
*Lychnis alba* (*Silene latifolia* ssp. *alba*)  
*Lycopodium annotinum* (stiff clubmoss)  
*Lycopodium clavatum* (running clubmoss)  
*Lycopodium complanatum* (groundcedar)  
*Lycopodium lucidulum* (*Huperzia lucidula*)  
*Lycopodium obscurum* (rare clubmoss)  
*Lycopodium tristachyum* (deeproot clubmoss)  
*Lycopus americanus* (American waterhorehound)  
*Lycopus uniflorus* (northern bugleweed)  
*Lycopus virginicus* (Virginia waterhorehound)  
*Lysimachia terrestris* (earth loosestrife)  
*Maianthemum canadense* (Canada beadruby)  
*Matricaria matricarioides* (*Matricaria discoidea*)  
*Medeola virginiana* (Indian cucumberroot)  
*Medicago sativa* (alfalfa)  
*Melampyrum lineare* (narrowleaf cowwheat)  
*Melilotus alba* (white sweetclover)  
*Melilotus officinalis* (yellow sweetclover)  
*Mentha arvensis* (*Mentha canadensis*)  
*Mimulus ringens* (ringen monkeyflower)  
*Mitchella repens* (partridgeberry)  
*Moneses uniflora* (single delight)  
*Myrica gale* (sweetgale)  
*Myriophyllum exallescens* (*Myriophyllum sibiricum*)  
*Nuphar variegata* (*Nuphar lutea* ssp. *variegata*)  
*Nymphaea odorata* (American white waterlily)  
*Nymphoides cordata* (little floatingheart)  
*Odontites serotinus* (*Odontites vernus* ssp. *serotinus*)  
*Oenothera biennis* (common eveningprimrose)  
*Oenothera fruticosa* (narrowleaf eveningprimrose)  
*Onoclea sensibilis* (sensitive fern)  
*Oryzopsis asperifolia* (roughleaf ricegrass)  
*Osmunda cinnamomea* (cinnamon fern)  
*Osmunda claytoniana* (interrupted fern)  
*Osmunda regalis* (royal fern)  
*Oxalis europaea* (*Oxalis stricta*)  
*Oxalis montana* (mountain woodsorrel)  
*Oxalis stricta* (common yellow oxalis)

*Phalaris arundinacea* (reed canarygrass)  
*Phleum pratense* (timothy)  
*Picea abies* (Norway spruce)  
*Picea glauca* (white spruce)  
*Picea mariana* (black spruce)  
*Picea rubens* (red spruce)  
*Pinus resinosa* (red pine)  
*Pinus strobus* (eastern white pine)  
*Plantago major* (common plantain)  
*Pogonia ophioglossoides* (snakemouth orchid)  
*Polygonatum pubescens* (hairy Solomon's seal)  
*Polygonum amphibium* (water knotweed)  
*Polygonum careyi* (Carey's smartweed)  
*Polygonum cilinode* (fringed black bindweed)  
*Polygonum lapathifolium* (curlytop knotweed)  
*Polygonum pensylvanicum* (Pennsylvania smartweed)  
*Polygonum punctatum* (dotted smartweed)  
*Polypodium virginianum* (rock polypody)  
*Polystichum acrostichoides* (Christmas fern)  
*Pontederia cordata* (pickerelweed)  
*Populus balsamifera* (balsam poplar)  
*Populus grandidentata* (bigtooth aspen)  
*Populus tremuloides* (quaking aspen)  
*Potamogeton epihydrus* (ribbonleaf pondweed)  
*Potamogeton natans* (floating pondweed)  
*Potamogeton pectinatus* (sago pondweed)  
*Potamogeton zosteriformis* (flatstem pondweed)  
*Potentilla anserina* (Argentina anserina)  
*Potentilla argentea* (silver cinquefoil)  
*Potentilla norvegica* (Norwegian cinquefoil)  
*Potentilla recta* (sulphur cinquefoil)  
*Potentilla simplex* (common cinquefoil)  
*Prunella vulgaris* (common selfheal)  
*Prunus pensylvanica* (pin cherry)  
*Prunus pumila* var. *besseyi* (western sandcherry)  
*Prunus serotina* (black cherry)  
*Prunus virginiana* (common chokecherry)  
*Pteridium aquilinum* (western brackenfern)  
*Pyrola elliptica* (waxflower shinleaf)  
*Pyrola rotundifolia* (*Pyrola americana*)  
*Pyrus americana* (*Sorbus americana*)  
*Pyrus floribunda* (*Aronia* X *prunifolia*)  
*Pyrus malus* (*Malus sylvestris*)  
*Pyrus melanocarpa* (*Aronia melanocarpa*)  
*Quercus rubra* (northern red oak)  
*Ranunculus acris* (tall buttercup)

Rhinanthus crista-galli (Rhinanthus minor ssp. minor)  
 Rhododendron canadense (rhodora)  
 Rhus radicans (Toxicodendron radicans ssp. radicans)  
 Rhus typhina (Rhus hirta)  
 Ribes glandulosum (skunk currant)  
 Ribes hirtellum (hairystem gooseberry)  
 Rubus allegheniensis (Allegheny blackberry)  
 Rubus hispidus (bristly dewberry)  
 Rubus idaeus (American red raspberry)  
 Rubus pubescens (dwarf red blackberry)  
 Rudbeckia serotina (Rudbeckia hirta var. pulcherrima)  
 Rumex acetosella (common sheep sorrel)  
 Ruppia maritima (widgeongrass)  
 Sagittaria latifolia (broadleaf arrowhead)  
 Salicornia europaea (Salicornia maritima)  
 Salix bebbiana (Bebb willow)  
 Salix gracilis (Salix petiolaris)  
 Sambucus canadensis (American elder)  
 Sarracenia purpurea (purple pitcherplant)  
 Scirpus atrovirens (green bulrush)  
 Scirpus cyperinus (woolgrass)  
 Scirpus pedicellatus (stalked bulrush)  
 Scirpus rubrotinctus (Scirpus microcarpus)  
 Scutellaria epilobiifolia (Scutellaria galericulata)  
 Scutellaria lateriflora (blue skullcap)  
 Sedum purpureum (Sedum telephium ssp. telephium)  
 Senecio aureus (golden ragwort)  
 Senecio vulgaris (common groundsel)  
 Silene antirrhina (sleepy silene)  
 Silene cucubalus (Silene vulgaris)  
 Sisyrinchium montanum (mountain blueeyed grass)  
 Sium suave (hemlock waterparsnip)  
 Smilacina racemosa (Maianthemum racemosum ssp. racemosum)  
 Smilacina trifolia (Maianthemum trifolium)  
 Solanum dulcamara (climbing nightshade)  
 Solidago graminifolia (Euthamia graminifolia var. graminifolia)  
 Spiraea latifolia (Spiraea alba var. latifolia)  
 Spiraea tomentosa (steeplebush)  
 Stellaria graminea (grasslike starwort)  
 Taraxacum officinale (common dandelion)  
 Taxilejeunea (taxilejeunea)  
 Thalictrum polygamum (Thalictrum pubescens)  
 Thelypteris thelypteroides (Thelypteris noveboracensis)  
 Thuja occidentalis (eastern arborvitae)  
 Tragopogon pratensis (meadow salsify)  
 Trientalis borealis (American starflower)

*Trifolium agrarium* (*Trifolium aureum*)  
*Trifolium arvense* (rabbitfoot clover)  
*Trifolium hybridum* (alsike clover)  
*Trifolium pratense* (red clover)  
*Trifolium repens* (white clover)  
*Tsuga canadensis* (eastern hemlock)  
*Typha angustifolia* (narrowleaf cattail)  
*Typha latifolia* (broadleaf cattail)  
*Utricularia cornuta* (horned bladderwort)  
*Utricularia purpurea* (eastern purple bladderwort)  
*Utricularia vulgaris* (*Utricularia macrorhiza*)  
*Uvularia sessilifolia* (sessileleaf bellwort)  
*Vaccinium angustifolium* (lowbush blueberry)  
*Vaccinium corymbosum* (highbush blueberry)  
*Vaccinium macrocarpon* (cranberry)  
*Vaccinium myrtilloides* (velvetleaf huckleberry)  
*Vaccinium oxycoccos* (small cranberry)  
*Vaccinium vitis-idaea* (lingonberry)  
*Valeriana uliginosa* (mountain valerian)  
*Vallisneria americana* (American eelgrass)  
*Verbascum thapsus* (common mullein)  
*Veronica officinalis* (common gypsyweed)  
*Veronica scutellata* (skullcap speedwell)  
*Veronica serpyllifolia* (thymeleaf speedwell)  
*Viburnum cassinoides* (*Viburnum nudum* var. *cassinoides*)  
*Viburnum lentago* (nannyberry)  
*Viburnum recognitum* (*Viburnum dentatum* var. *lucidum*)  
*Viburnum trilobum* (*Viburnum opulus* var. *americanum*)  
*Vicia cracca* (bird vetch)  
*Vicia sepium* (bush vetch)  
*Viola adunca* (hookedspur violet)  
*Viola cucullata* (marsh blue violet)  
*Viola pallens* (*Viola macloskeyi* ssp. *pallens*)  
*Viola septentrionalis* (northern blue violet)